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Lubrication

A Technical Publication Devoted to the Selection and Use of Lubricants

THIS ISSUE

AUTOMOTIVE HYDRAULIC TRANSMISSIONS

TEXACO

REG. T. M.

PUBLISHED BY

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LUBRICATION

A TECHNICAL PUBLICATION DEVOTED TO THE SELECTION AND USE OF LUBRICANTS

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Automotive Hydraulic Transmissions

The driver of the modern automotive vehicle is interested in power. If he is technical in his interest he is concerned with the "brake" horsepower delivered by his engine at its flywheel; otherwise his interest relates power to "pick-up," hill climbing and speed. The power delivered by an engine is simply the product of a constant, the speed of the engine and its turning effort or "Torque."

The torques of steam, air and hydraulic engines, and of series electric motors are greatest at the instant of starting, diminishing as the speed increases. As will be seen later, this characteristic would be extremely valuable in an automotive engine. However, early attempts to utilize these engines for automotive use were at least temporarily defeated by the necessity for conquering a variety of associated problems such as automatic boilers, large capacity compressors or pumps, and compact and light-weight generators; consequently the development of such engines for automotive use lagged far behind the Diesel and gasoline internal combustion engine.

Unfortunately for automotive application, the torque of a gasoline or Diesel engine is zero at zero speed.

As illustrated by the lowest curve in Figure 1, the torque required at the driving wheels of an automobile to move it along a level road will increase at an increasing rate as the speed is increased, the rate of increase being largely due to increasing air resistance.

At first thought it would appear possible to couple the engine directly to the driving wheels; this actually was done in at least one early racing car which had a very powerful low speed engine. A considerable excess of engine torque over the wheel requirement must be available however, to permit the car to accelerate to a higher speed, the amount of excess obviously, being proportional to the desired acceleration or car agility. Similarly additional torque reserve is needed when the vehicle weight is increased or when steep grades must be ascended. Since engine torque attains a maximum at relatively low car speeds it is impractical and uneconomical to obtain the desired torque reserve by merely installing a more powerful engine, consequently the designer must find other means of increasing or multiplying wheel torque.

With a given amount of available power, the delivered torque can be increased by decreasing the speed at which it is delivered. The classic method of accomplishing this in an automobile is to interpose a series of reduction gears (transmission and differential) between the engine and the wheels. Since the engine durability decreases rapidly as its speed is allowed to increase, engine speed must always be kept below a certain value, so the possible operating range in any given gear is severely limited. The three sharply curved lines in Figure 1 illustrate the available torque in low, intermediate and high gears of a typical automobile. To obtain maximum acceleration throughout the speed range of a conventional transmission the driver would have to shift gears at points "A" and "B". At these points however, the engine would be racing at equivalent high-gear car speeds of 77 and 84 miles per hour respectively, although the car would be actually moving at 30 and 46 miles per hour. Obviously, no engine could long withstand such treatment.

For reasons discussed above, the ratio between engine torque and the required wheel torque varies widely; it therefore becomes necessary to approximate a balance between required and available

torque by providing several reduction gear ratios in either or both the transmission and differential. For example, in an average passenger car of conventional design the ratio of engine speed to the rear wheel speed varies between 14 to 1 in low gear and 4 to 1 in high gear (or so-called "direct drive"). Or from another viewpoint, it is necessary to multiply engine torque from four to fourteen times before applying it to the driving wheels. The problem of properly selecting and promptly engaging the appropriate gear under varying road conditions is no mean one for even an expert driver. Is it possible to accomplish, or at least simplify this problem by automatic means?

So far we have chosen to slight two other important facts:

1.—A gasoline or Diesel engine produces zero torque at zero speed.

FIGURE 1

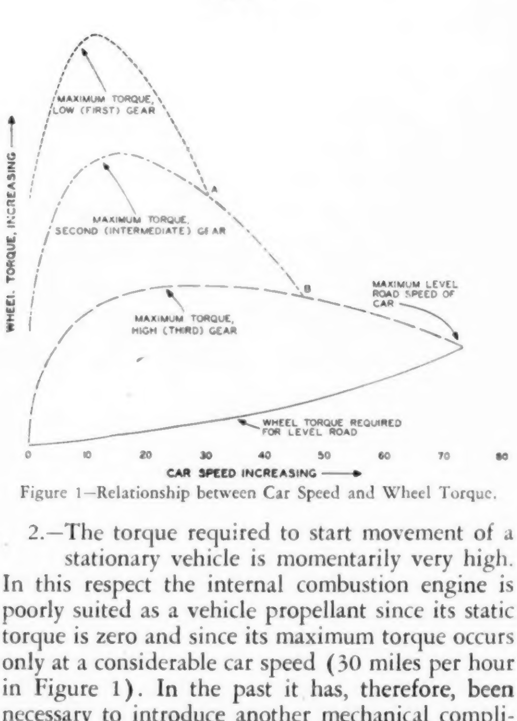


Figure 1—Relationship between Car Speed and Wheel Torque.

2.—The torque required to start movement of a stationary vehicle is momentarily very high. In this respect the internal combustion engine is poorly suited as a vehicle propellant since its static torque is zero and since its maximum torque occurs only at a considerable car speed (30 miles per hour in Figure 1). In the past it has, therefore, been necessary to introduce another mechanical complication called a "clutch" which with careful manipulation will allow the engine to be started and raised to a reasonable torque-producing speed before more-or-less gradually applying such torque to the wheels.

In summation, the basic problem in building a motor vehicle is to find simple means of generating, applying and automatically adjusting adequate torque to the driving wheels. The problem has not yet been completely solved but considerable progress has been made. The purpose of this and succeeding issues is to describe a number of ingenious and effective partial solutions of a hydraulic nature which have been applied to American automotive vehicles during recent years.

THE FLUID COUPLING

The fluid coupling, also called "fluid drive," "fluid flywheel" or "fluid clutch" is the basic hydraulic mechanism in several successful hydraulic transmissions, and in at least one instance (a small motorcycle) it even comprises the entire transmission. As may be seen in Figures 2 and 3, the fluid coupling consists essentially of a bowl-shaped driving member or "impeller" and a very similar driven member or "runner," the open sides of which are mounted in close proximity on concentric but completely independent shafts. Both the impeller and the runner are fitted with a number of equally spaced radial vanes welded or riveted to each bowl and forming compartments. Each assembly closely resembles a grapefruit half when the pulp has been removed to expose the dividing membranes. In order to avoid the possible generation or transmission of undesirable hydraulically-induced vibrations, the impeller and runner are usually fitted with an unequal number of vanes. Figures 2 and 3 illustrate fluid couplings used in popular cars.

The coupling is filled approximately two-thirds full with a special fluid which forms the sole torque-transmitting medium between the impeller and runner. No mechanical connection exists between the runner and impeller. If the coupling fluid were drained out, the coupling would be unable to transmit any torque. If the runner is held stationary (as it is when connected to the rear wheels of a stationary automobile) and the impeller is revolved slowly by the engine, centrifugal action causes the hydraulic fluid to flow radially outward to the largest diameter of the impeller, across the gap to the runner and back through the runner compartments towards the center of the coupling. As the hydraulic fluid is thrown from the impeller into the runner, it develops a torque in the runner which is approximately equal to the square of the impeller's speed.

Figure 4 illustrating the general characteristics of a fluid coupling shows that as the runner-impeller speed ratio is increased, the power transmitted to the runner also increases rapidly, until inertia is overcome and the automobile moves forward in smooth acceleration. When the car attains equilibrium speed corresponding to the chosen throttle opening, the impeller and runner speeds become practically equal, and the coupling then functions as a solid but resilient connection.

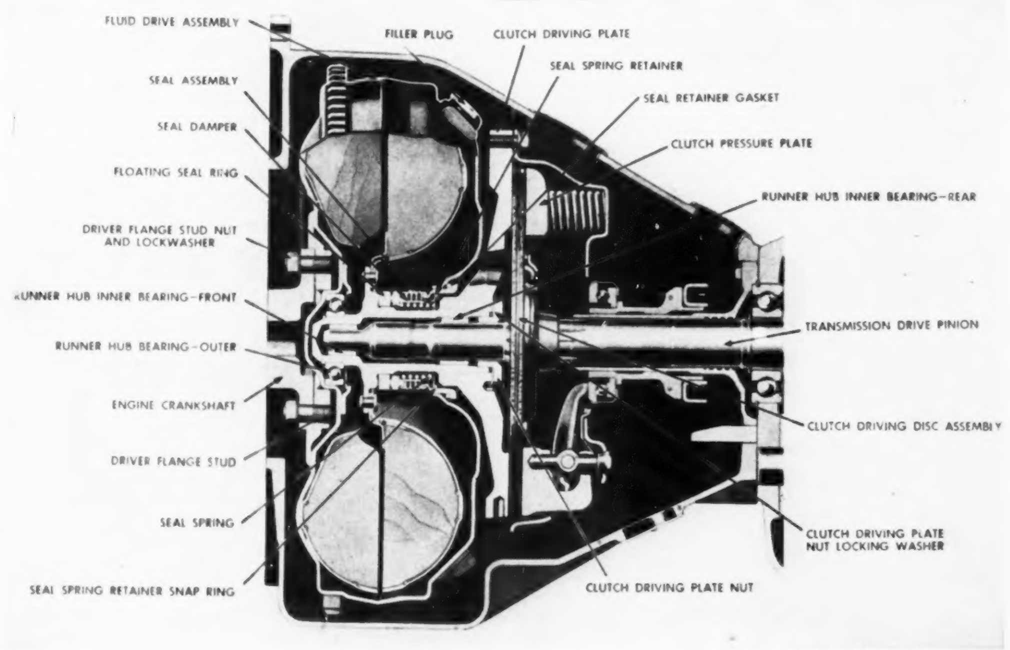
Two other important fluid coupling characteristics are:

1.—A fluid coupling does *not* multiply or increase the torque applied to it (which is accom-

plished by the deceptively similar torque convertor to be discussed in a later issue).

2.—The coupling transmits practically all torque exerted on it when the runner speed approximates the impeller speed.

Since the torque capacity of a fluid coupling increases as the 5th power of the impeller diameter, only a slight increase in size will give a tremendous increase in torque. For example, a coupling only 13" in diameter will easily and efficiently transmit the full torque from a 110 HP engine. This characteristic permits the designer to easily incorporate a fluid coupling within the engine flywheel (whence foot throttle. Furthermore, the fluid coupling dissipates excess heat only in proportion to the difference between the impeller and runner speeds and such speed difference is practically zero throughout the normal driving speed range of the automobile. Unlike the conventional clutch, the fluid coupling provides an elastic cushion between the engine and rear wheels which not only reduces peak loads on all components of the power train with resulting improvement in service life, but also contributes to the general quietness of the automobile by partially damping out vibrations that would otherwise be conducted and perhaps amplified by associated parts.



Courtesy of The Chrysler Corporation.

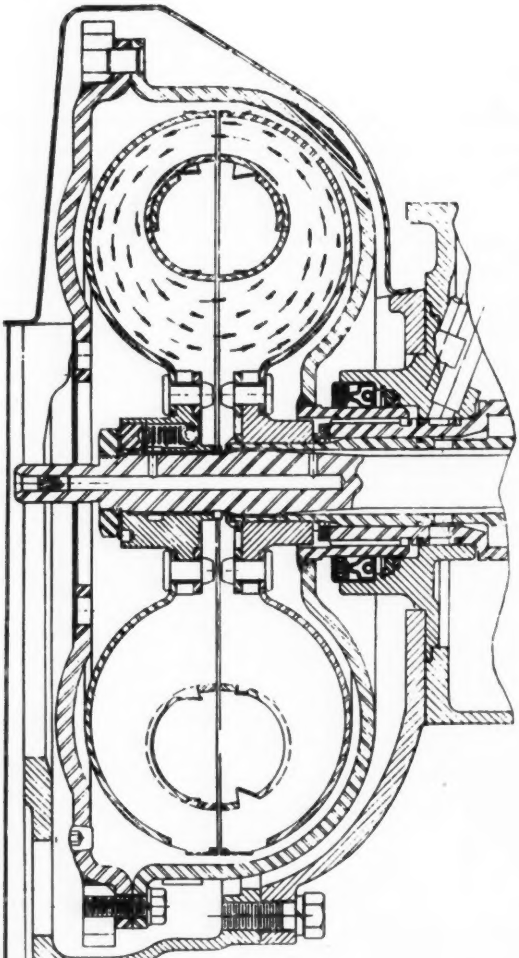
Figure 2—Chrysler Type Fluid Coupling and Clutch.

the name "Fluid Flywheel"), or to place it within the clutch housing, or even to install it within the transmission.

Because of its ability to transmit torque smoothly throughout impeller-runner speed ratios between zero and one, the fluid coupling may be used to complement or even replace a conventional clutch. It may also be used to eliminate one or two of the gear ranges otherwise used in a conventional transmission. Surplus energy dissipated as heat in a fluid coupling is believed to be comparable to that of a standard clutch and the latter is at a disadvantage in a partly engaged position since experience and skillful operation are required to transmit torque smoothly. The fluid coupling on the other hand, applies a steady torque that is easily adjustable throughout wide range by merely manipulating the

Even at engine idling speed (300-450 RPM) the impeller of a fluid coupling may impart sufficient torque to the runner to move or "creep" a car on level pavement. Under most circumstances this characteristic is advantageous. For example, a car equipped with a fluid coupling is easily controlled in parades or other slow moving traffic. When, as is so frequently the case, a traffic signal is located at a high up-grade, the car can be easily held on the grade by slightly depressing the accelerator and will move on rapidly when the light changes by merely depressing the accelerator further. In other words, the normal but highly inconvenient use of a parking brake to temporarily prevent the car from rolling backwards is eliminated by the fluid coupling. A word of caution should be given in this particular: A fluid coupling should be pre-

vented from operating with the runner stationary for more than approximately five (5) minutes by shifting the associated transmission into neutral, to avoid overheating of the hydraulic fluid.



Courtesy of General Motors Corporation.
Figure 3—Cadillac-Oldsmobile Type Fluid Coupling.

The hydraulic fluid used in a fluid coupling usually consists of a highly refined light mineral oil blended with one or more additives to impart a number of necessary but rather special qualifications.

The viscosity of the fluid should be as low as is consistent with complete lubrication of the component bearings, gears and the coupling seal. Contrary to popular supposition any attempt to use a higher viscosity fluid would actually reduce the torque-transmitting ability of the coupling since torque-transmission is dependent upon a high circulation of fluid between the impeller and runner and is not caused by any viscous drag between the two. The viscosity index or ability to maintain viscosity over a considerable temperature range should be reasonably high. For similar reasons the pour or congealing point of the fluid must be below the atmospheric temperature at which the coupling is expected to operate.

The fluid must resist oxidation, evaporation, and formation of sludge to a high degree. All the conditions leading to undesirable oil oxidation are present in a fluid coupling; i.e. an excess of air, moderately high temperature and metal catalysis. It will be recalled that fully one-third of the couplings volume is air which is violently mixed with the fluid during operation. In many designs the all-important seal consists of a flexible copper bellows carrying a carbon-graphite seal ring which is pressed against a highly polished steel mating surface by means of a contained spring. The fluid must not corrode or otherwise damage any of the materials which it regularly contacts. Since metallic copper is an active oxidation promoter an ordinary straight mineral fluid would tend to develop organic acids which would attack and destroy the bellows. For the above reasons the modern hydraulic coupling fluid contains special additives which enable it to resist oxidation.

A hydraulic coupling fluid must avoid foaming by quickly rejecting any entrained air since oil foam is neither an effective hydraulic fluid nor a lubricant. The fluid must not only be practically free from moisture when manufactured but also should possess the ability to separate from and reject any water that may subsequently contaminate it. If the hydraulic fluid is also used to lubricate an associated transmission it may be required to possess moderate extreme pressure or oiliness characteristics.

ELECTRICALLY-CONTROLLED HYDRAULIC TRANSMISSIONS

One example of an electrically-controlled hydraulic transmission is exemplified by the Chrysler hydraulically operated transmission which is furnished as special equipment on current Chrysler and DeSoto cars. This transmission will be described in detail since it not only furnishes a good example of a relatively simple semi-automatic mechanism but an explanation of its operation should facilitate understanding of the more complex transmissions to be described in succeeding issues.

Engine torque is delivered to the transmission through a fluid coupling bolted to the flywheel and thence through a conventional single plate "safety" clutch. The word "safety" is applied to this clutch since it is largely used only during the initial engagement of the transmission at the beginning of the trip or during the selection of a speed range, or when reverse gear is used. During 95% of or-

dinary driving under ordinary conditions the safety clutch is not used. To those, however, who learned to drive an automobile several years ago, the mere physical presence of a familiar clutch pedal is said to provide some degree of psychological comfort.

The mechanical portion of the transmission comprises a main shaft, counter shaft, and reverse idler shaft which carry helical constant-mesh gears and two shiftable clutch sleeves necessary to provide four forward speeds and one reverse. The four forward speeds are divided into two driving ranges, first and second speeds being contained in the low range while third and fourth are in the high range. By means of a steering post lever the driver may select either range; subsequent shifting between the two speeds within that range is automatically provided by the control system. The principal components of the transmission and the automatic control system are illustrated in Figure 5.

Before taking up a discussion of this transmission, the reader should be advised that the third speed gear (Number 3, Fig. 5) is splined to and rotates with the direct speed clutch sleeve (Number 9)—the assembly being free to rotate on the mainshaft. Similarly, the first speed gear (No. 5) is free to rotate independently on the mainshaft until connected to it through the manual clutch sleeve (No. 10) which is splined to the mainshaft. The free wheeling gear (No. 2) at the forward end of the countershaft contains a free wheeling unit or "one-way clutch" which permits it to be driven by the main drive pinion (No. 1) but prevents it from driving the pinion. The free wheeling control sleeve (No. 12) is operated by the direct speed clutch sleeve (No. 9) and is provided as additional insurance that the free wheeling unit will always be inoperative when the transmission is in either 2nd or 4th speed. It should be noted that this free wheeling provision will not permit the engine to brake the car when the transmission is in either 1st or 3rd speeds.

The steering post range selector lever is mechanically linked with the "manual" control sleeve (No. 10 in Fig. 5) to enable shifting the latter to either a forward, neutral or rearward position. In its forward position (which is actually illustrated in Figure 5) the manual sleeve meshes with the rear of mainshaft gear No. 3 thereby establishing the high range which includes the 3rd and 4th gears that are used during 95% of normal driving. When in 3rd speed, torque from the fluid coupling is transmitted by the main drive pinion (No. 1) through gear Nos. 2 and 4 on the countershaft and thence back to the main shaft and rear wheels through gear No. 3. The gear ratio in 3rd speed is designed to provide very effective acceleration and hill climbing ability under average conditions.

Fourth speed is obtained by the automatic shifting of the direct speed clutch sleeve (No. 9) to engage gear No. 1 whence torque is transmitted straight along the mainshaft to the rear wheels. Since the free wheeling unit within gear No. 2 is released, the countershaft is driven idly through gears 3 and 4.

In its central or neutral position the manual clutch sleeve permits both the 3rd and 1st speed gears (Nos. 3 and 5) to rotate freely on the mainshaft, hence no torque can be transmitted. The central neutral position of the manual sleeve is also utilized to permit the separate manual engagement of the

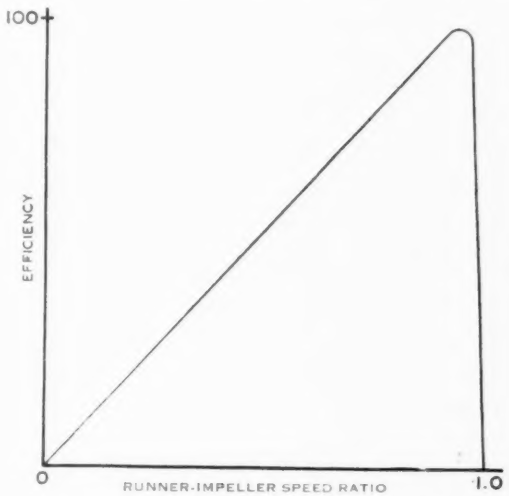


Figure 4—General Characteristics of a Fluid Coupling.

reverse idler gear (not shown in Fig. 5) with gear No. 7 by means of a separate shift fork. Since the reverse idler gear is mounted on a third shaft and is constantly in mesh with gear No. 6 on the countershaft, a shift into reverse is facilitated because additional meshing with only one gear instead of the usual two is all that is required from the driver.

In its rearmost position the manual clutch sleeve (No. 10) engages first speed gear (No. 5) and thereby establishes the low speed range which includes first and second speeds. In first speed, the direct speed clutch sleeve (No. 9) is in its rearmost position (as actually illustrated in Fig. 5) and torque is transmitted from main drive pinion No. 1 through countershaft gear Nos. 2 and 6, thence back to main shaft gear No. 5 and the connected rear wheels. In second speed, the direct speed clutch is in its forward position and torque is transmitted from main drive pinion (No. 1) to main shaft gear (No. 3) countershaft gears 4 and 6 and thence back to mainshaft gear No. 5 and the connected rear wheels.

The forward or direct speed clutch sleeve is auto-

matically shifted to its forward position by means of hydraulic pressure on a piston and is automatically returned to its rearward position by means of a strong spring when the control system causes the release of hydraulic pressure. In its forward position the direct-speed clutch sleeve meshes with the main drive pinion gear (No. 1, Fig. 5) and the transmission is in second speed of the low speed range or fourth speed of the high speed range, the speed being dependent upon position of the manual sleeve (No. 10) that was pre-selected by the driver. Since the direct speed sleeve should not be allowed to attempt to mesh with the main drive pinion until both are at the same speed, the designers have interposed a blocker ring (No. 8) which prevents engagement until synchronism has been established.

The transmission incorporates its own rotor type oil pump which is driven from a gear on the extreme rear end of the mainshaft (not shown in Figure 5), and, therefore, always runs at a speed proportional to the car speed. The pump is submerged in the transmission oil, and is of sufficient capacity and discharge pressure (app. 50 lbs. square inch) to provide quick operation of the hydraulic shift piston when demanded by the control system. The pump, therefore, operates only when the car is moving forward, and will not permit an automatic shift when the car is backed up. A pressure relief valve is provided to regulate discharge pressure and to bypass the surplus discharged oil back to the pump intake.

The control system is of conspicuous ingenuity since it not only provides automatic gear shifting to meet the normal requirements of the road, but allows the driver to overrule or "take over" the controls whenever he desires. Furthermore the driver is prevented from attempting certain actions that would be injurious to the car.

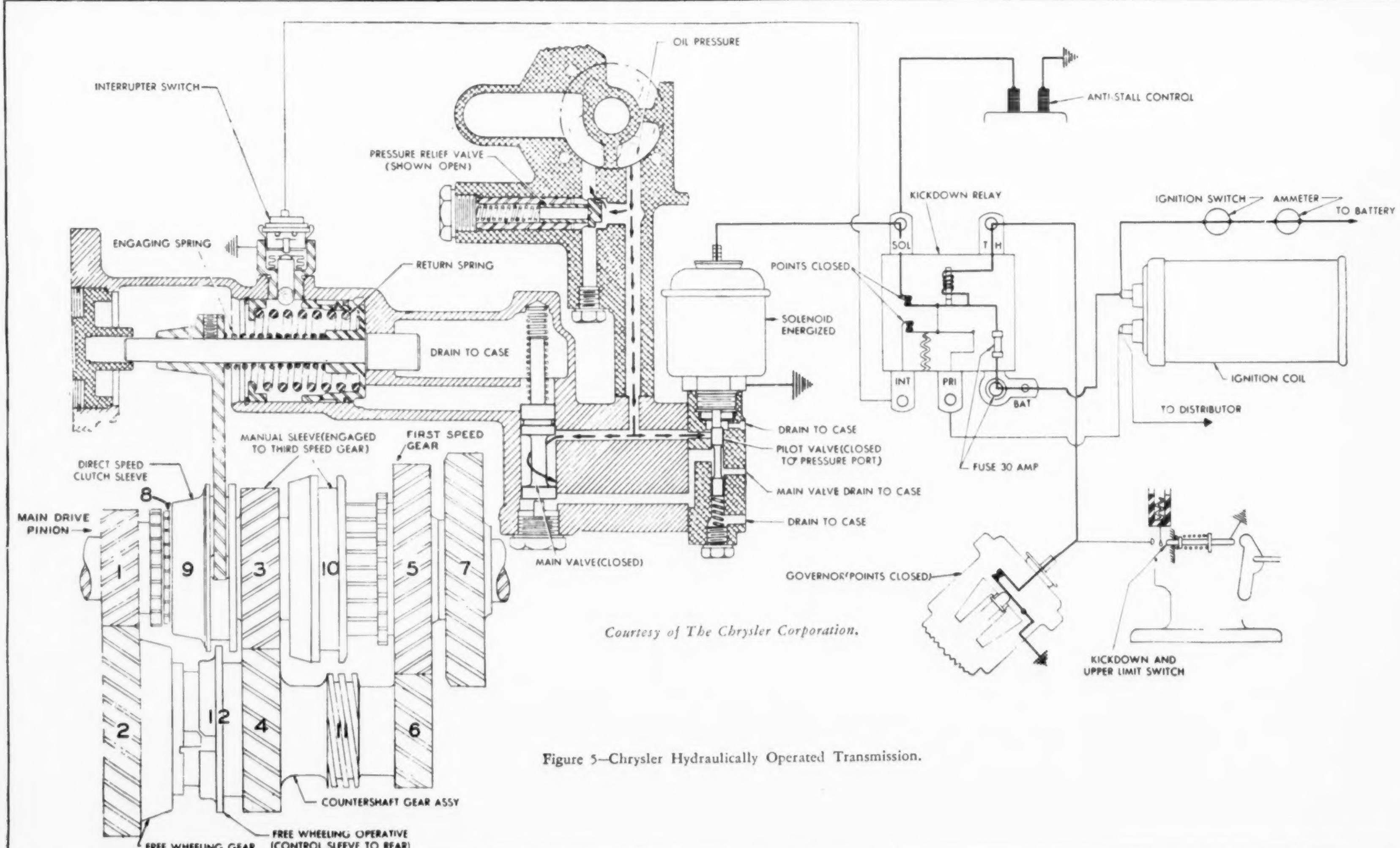
In addition to the shift piston and oil pump mentioned above, the hydraulic portion of the control system includes a small quick-acting pilot valve and the main hydraulic control valve, both being of the piston type. Reference to Figure 5 will show that the pilot valve is normally held in its uppermost position by means of a spring, but may be forced to its lower position against spring pressure by energizing the electric solenoid attached to it. On the other hand, the main valve is normally held to its lower or closed position by spring pressure, and will remain there as long as the pilot valve is down. In this position the main valve cuts off oil pressure to the shift piston which consequently returns to its rearward position under spring pressure, and shifts the gears from fourth speed to third (or from second to first). In other words such a "downshift" occurs whenever the solenoid receives current. Regardless of the position of the pilot valve, however, the transmission will return to first or third speed when the car is parked and the ignition is turned off, since no oil pressure is then available to motivate the shift to a higher gear.

Before proceeding to consideration of the electrical portion of the control system the reader should consider the interrupter switch which is mounted adjacent to the hydraulic shift piston. Those drivers who have attempted to shift a conventional transmission out of gear when the car is moving will remember that considerable force is required unless the applied engine torque is eliminated as by depressing the clutch pedal. Similarly, in the DeSoto or Chrysler transmission it is necessary to relieve the torque load on the teeth before the synchro-sleeve (No. 9) can be disengaged for a down shift into third (or first) gear. The interrupter switch in connection with the relay is designed to momentarily interrupt or cut off the engine ignition current by producing a ground in parallel with the distributor points. Examination of Figure 5 will show that the outer edge of the hydraulic shift piston together with a groove in its skirt form a cam surface which raises and lowers the interrupter switch ball whenever the piston passes it in either direction but an engine interruption is only obtained on the return stroke due to the series connection of the switch and relay points. The dimensions of the cam and the speed of the hydraulic piston are such that the engine ignition circuit is interrupted for only three or four individual cylinder explosions; consequently the infinitesimal engine hesitation caused by the interrupter switch while amply sufficient to accomplish its purpose can not be detected by the average driver.

In addition to the pilot valve solenoid and interrupter switch, the remainder of the control system contains a relay, governor, ignition switch, kickdown and upper limit switch and an anti-stall control which have the following important functions. From the wiring diagram in Figure 5 it will be noticed that all of these remaining devices are electrically connected to the pilot valve solenoid and that any one, or all in concert, may control the solenoid and thereby either cause or prevent an automatic gear shift.

The relay is an automatic switch which contains two sets of contact points that are normally open. When the relay winding is energized (as indicated in Figure 5), both sets of points are closed and current may flow through them. The upper pair of points control the solenoid and hence the pilot valve, main valve and hydraulic shift piston.

The governor is also an automatic switch containing one set of contact points which are opened or closed by centrifugal action of counterweights. The governor is one of the devices (governor, kickdown switch, upper limit switch) which exer-



Courtesy of The Chrysler Corporation.

Figure 5—Chrysler Hydraulically Operated Transmission.

cise control over the automatic shift. The governor is geared to countershaft gear No. 11 and therefore runs at speeds proportional to the rear wheels. The governor contact points are normally closed but are forced open and break the governor circuit whenever the car speed exceeds 12 to 14 miles per hour in third speed (or 6-7 miles per hour in first speed). During subsequent deceleration the points will close again at speeds approximately two miles per hour less than the opening speeds.

The ignition switch is of the usual type and is mentioned only to point out that when it is opened with the car moving, and regardless of the other controls, the transmission will shift to fourth (or second) speed but will return to third (or first) speed as soon as the car stops.

The kickdown switch is contained in a small housing adjacent to the carburetor throttle shaft. Its single set of contact points are held open by spring pressure, and are closed only when the accelerator pedal is fully and firmly pressed to the floor board. The purpose of this switch is to enable the driver to overrule the governor and to obtain a shift from fourth to third speed by merely depressing the accelerator. For example, when ascending a grade in fourth speed it would be inconvenient to have to wait until car speed decreased to 14 miles per hour and the governor caused a normal shift from fourth to third speed. With the kickdown switch, the driver can immediately force a downshift whenever he desires with one exception—if the upper limit switch permits.

The upper limit switch is also located in the carburetor and consists of a single contact point interposed between the twin contact points of the kickdown switch. The single point is connected to a spring-loaded piston, the upper side of which is connected to a small hole at the "throat" or smallest internal diameter of the carburetor venturi tube. One characteristic of a venturi tube is that it will develop a vacuum at its throat which is proportional to the amount of air passing through the throat. With the throttle wide open, the amount of air passing through an engine's carburetor is proportional to the engine's speed. The upper limit switch point will, therefore, be gradually withdrawn from between the kickdown switch points and will thereby prevent the kickdown switch from functioning whenever the car speed is more than approximately 40 miles per hour. The upper limit switch is therefore a safety device designed to prevent the driver from dangerously overspeeding his engine by attempting a downshift at high car speeds.

Practically all driving with this transmission is done in the third and fourth speeds of the high range. After starting the engine with the range selector lever in neutral, the safety clutch is depressed, the selector lever moved to high range, the clutch re-engaged and the accelerator depressed as usual—clear to the floor if you wish a jack-rabbit start. In such a start, the engine will immediately and noticeably increase its speed as the fluid coupling performs its function until the car "catches up with the engine". The increase in engine speed and the apparently effortless acceleration provided by the fluid coupling afford a unique experience to a driver who has become accustomed to the unyielding and uncompromising rigidity of a conventional clutch and transmission.

When the car reaches any speed between 14 and 40 miles per hour, the driver merely lets up the accelerator until the transmission emits a faint click, and then puts the accelerator back to the floor (if he must continue to be spectacular). The time required for the transmission to shift into fourth speed will increase slightly as the car speed increases, but normally takes less than two seconds — considerably less than a trained driver could accomplish a comparably quiet shift with a conventional transmission. In very hilly "roller coaster" terrain, or in traffic, the driver may find it advantageous to operate entirely in third speed. During slow driving or on a long hill, the transmission will automatically downshift to third speed whenever the car speed drops below 12 miles per hour, but the driver may anticipate the automatic downshift t some higher speed and thereby maintain a higher average driving speed by briefly depressing the accelerator.

When descending ordinary grades the fourth speed permits the engine to exert considerable braking effect. When very steep down grades are encountered, a shift to second speed of the low range will permit the engine to exert its maximum braking effect.

The low speed range is but little used, but can be valuable in deep snow or mud, or whenever the maximum available torque is desired.

If a run-down battery should require starting the engine by pushing or pulling the car, the driver must remember to briefly disengage and re-engage the safety clutch when the car has attained a speed of over 14 miles per hour. Unless this simple requirement is accomplished, the transmission will remain in the freewheeling third (or first) speed, and the car will not be able to rotate and start the engine. If conditions warrant, the same action can be accomplished at a car speed above 7 miles per hour if the transmission is shifted to the low range.

Because of generous gear dimensions, the desirability of insuring positive cold weather operation of the hydraulic shift system, and because the associated fluid coupling is independently lubricated, the lubrication requirements of the Chrysler transmission are uniquely simple: The manufacturer recommends the use of SAE 10W engine oil.

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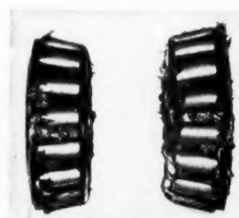

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